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**Published**
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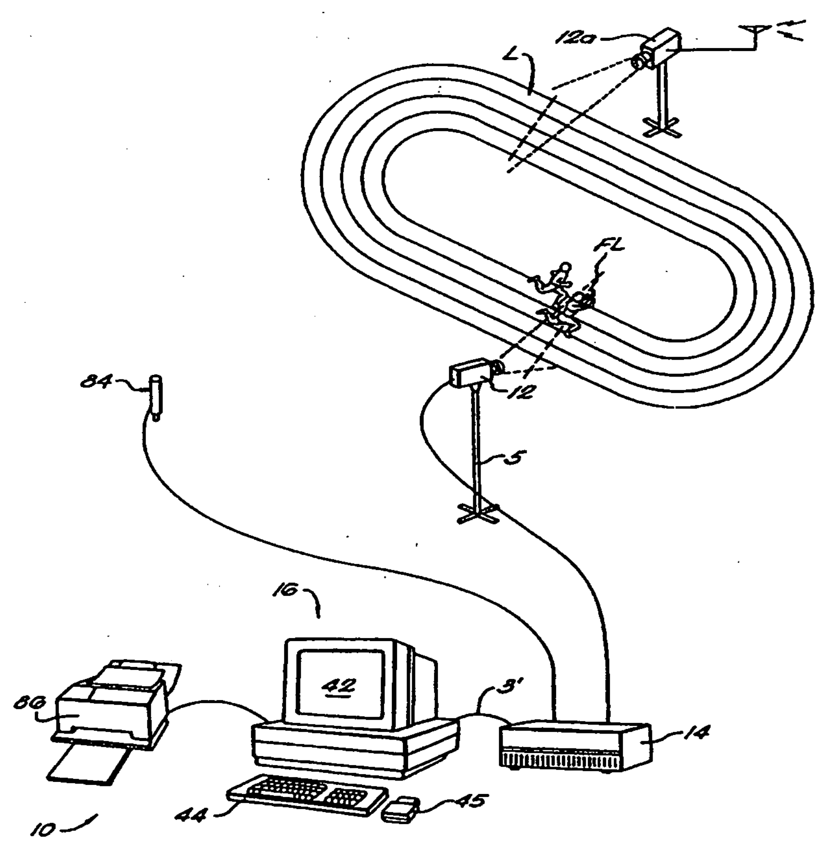
**(54) Title:** CAMERA WITH OBJECT RECOGNITION/DATA OUTPUT

**(57) Abstract**

A line scan digital camera (12) is directed at a station for recording and displaying a time-sequential scene. The digital camera (12) takes a sequence of digital image frames representative of one or more bodies crossing a plane (FL) in space, wherein each frame represents a line image of the body, thus forming a fractional part of the scene, and the set of time-successive frames forms a recognizable image on an external display (42). In a preferred embodiment, the camera (12) is an event camera at a competition, and it images the finish line (FL) or an intermediate station (L) to determine crossing times of contestants. The camera (12) is also adapted to robotic vision applications for stations at irregular transport lines, and for mid-course identification and reporting along race tracks, transport lines and traffic environments.



# CAMERA WITH OBJECT RECOGNITION/DATA OUTPUT

## Technical Field

The present invention relates generally to systems which monitor and record motion events, and it relates to cameras and systems for time-sequential imaging and display, with application in numerous fields. Most particularly, the invention provides a station imaging camera and system useful for measuring timed sporting events and imaging movement along defined tracks at stations. The invention also relates to systems and methods for generating a scene by compiling successively-scanned line objects, as described for example in applicant's commonly-owned United States patents 5,552,824 and 5,657,077.

Prior art systems employing standard photographic techniques to monitor the finish line of a race are known. In such a system, typically one or more cameras equipped for high resolution imaging view the finish line and capture sequential pictures at a high rate for later inspection by a judge or other interpreter. However, this process is cumbersome, wasteful, and time-consuming, in that it requires, for example, an apparatus of photographic film and paper, processing chemicals, and image enlargers or projection optics to be employed with their respective methods of operation, development and finishing. Consequently, most races rely on human judges and revert to "photo-finish" technology only in extremely close or important events. The Specialty Instrument Corporation provides a number of electronic and photo-finish systems of this type marketed under the trademark Accutrack. U.S. Patent No. 3,829,869 exemplifies one such Accutrack system.

Because of the problems with the "photo-finish" technology, numerous other systems for monitoring racing events have been developed. However, these other methods and systems for timing sporting events present new difficulties. Video systems which record and display races in a standard television or video format are popular, but regardless of the particular implementation of these systems, a portion of the electronic image remains on an analog medium, such as recording tape. Since analog data from the systems consists of a continuum of information over time, it is relatively difficult to accurately apportion to a unique time interval. It is even more difficult to access a particular moment in time in the recorded sequence because the associated system must search the storage medium, typically having a long physical length in a spooled format, e.g., a video cassette. This presents both limitations and difficulties for users wishing to

linear/temporal or *t,y-dimension* image may be formed that bears a readily interpretable similarity to the customary optical spatial or *x,y-dimension* image of the scene. As set forth in applicant's above mentioned patents, the data stream from such cameras can be used to detect and deal with moving objects to provide high temporal and spatial resolution in real time. This entails transmission of a generally continuous stream of line image data to a processing system, which then attends to the annotation, indexing, compression and storage of the relevant views so that a small sub-portion of relevant views can be placed in digital random access storage and readily recalled, typically within minutes or seconds of the original image acquisition, for detailed inspection. However, effective use of such line-imaging camera systems has required extensive software-mediated data handling by a trained technician operating the system, and great demands are imposed on the data transmission and synchronization for effecting image assembly, time synchronization, and image frame recording and access.

It is, accordingly, an object of the invention to provide an improved camera and system for recording and displaying a time-sequential scene of bodies crossing a plane along a track.

These and other objects will become apparent in the description below.

## Summary of the Invention

The invention features, in one aspect, a camera for forming a time sequential scene of bodies moving across a plane in space, wherein the camera recognizes the appearance of an object within its limited field to trigger or flag its image output stream. The system includes at least one camera which is aimed to image objects crossing a line of interest, wherein the camera time-sequentially captures the object by imaging it onto an array of detector elements and converts the sampled signal into a digital line image, or frame, which passes to a frame buffer. Each digital image frame uniquely represents a fixed slice of the moving scene at a moment in time. A processor is situated within the camera, and communicates with the buffer, processing information from corresponding pixels or larger blocks of time offset frames to detect an object which has entered the line field of view and responsive thereto, controls the image data output stream or produces data coordinated with the image stream. For example, in one aspect, the camera detects arrival or departure of objects in the image field and thereupon operates to produce or enable an image data output stream, or to annotate the stream and enhance its information content by indicating such detection. In a basic

features in the correct order before triggering the finish line time determination, or by otherwise confirming the presence of an object, the camera avoids falsely triggering, for example on a shadow of a back-lit runner that may precede the actual crossing.

In yet another or further embodiment, the processor processes frame data to detect patterns or markings on the imaged objects, such as numbers identifying the contestants, and the output frames in which these objects or indicia were detected are flagged or indexed with the detected identifiers. The line camera may be set up at a plane of interest, such as the finish line of a race or an intermediate position along the track. In this case, the frame times may also be processed with the flagged identifiers at the observed plane, either the finish line or an intermediate position, to quickly show rankings or relative positions, speed or other ratings for immediate display in an automated manner without waiting for a judge's inspection of the digitally reconstructed images as required in previous image timing systems. The camera output augmented with this data thus directly interfaces with a computerized race management system so that desired frames are quickly accessed by their index information for review. A user at the computer console can command a variety of functions provided by the invention to manipulate and analyze the captured scene, most particularly to display any portion of the scene of bodies moving across the plane and access an associated time and/or identities of contestants for each frame within the sequence of line crossing images.

The system of the invention is particularly useful in recording and managing the official times of objects or entrants crossing a finish line in a digital race management system since it both preserves all imaging information and simplifies the storage, transmission and selective retrieval of finish line information. A user can therefore record and display the bodies crossing the plane of interest, i.e., the finish line, with accuracy while enhancing the ability to immediately employ information embedded in the images in real time, both to review and edit the stored images for finish determinations, and to effect fast automated display of unreviewed results. The invention thus provides an object-controlled compression and information enhancement of the camera output data.

The system constructed in accordance with the invention also provides, in another aspect, an in-camera memory subsystem communicating with an in-camera processor, wherein blocks of frame data are processed to detect an object, to detect a background, and to control start time and/or end time for active imaging segments which are to be transmitted out of the camera for analysis. According to this aspect of the

FIGURE 1 illustrates a camera 12 in accordance with the invention mounted in a system for imaging and recording a sequence of bodies crossing a plane in space, which illustratively is shown containing the finish line FL of a track. As discussed further below in connection with certain embodiments, a camera 12a may also be positioned to image an intermediate line L in a race monitoring system. In other aspects the system may be positioned to image a station in a robotic process line; however, for clarity of exposition below, the example of an event recording camera 12 is discussed in detail.

As shown in FIGURE 1, the camera 12 is mounted on a stand S which places the camera above and to the side of the finish line, with the camera itself oriented and aligned such that the finish line is imaged onto a linear sensing array, the output of which is electrically scanned or sampled at a high rate to produce a time-resolved image data stream. Preferably the camera is positioned in the vertical plane of the line FL, and aligned so that the plane is projected onto the sensing array. For example the camera may be above and to the side of the track, or in certain cases may be mounted overhead. The camera is connected in a race management system 10 which includes the digital camera 12 and an image management computer 16 connected to various display or recording devices and interfaces.

As shown more fully in FIGURE 1A, the camera 12 of the present invention possesses an objective lens or optical assembly 15 which images a line portion 18 of the object field of its objective lens 15 onto an array of detector elements 20, preferably a Line Scan Charge Coupled Device (LS-CCD) having a pixel length of one thousand to several thousand pixels. An imaging controller 22 samples the detected light level at the detector elements 20 at successive times and amplifies the output signal with a gain controlled detector amplifier 24 and digitizes the processed signal with an A/D converter 26, to acquire successive frames of image data. The signal frames, each representing a line of pixels, are taken at a rate above several hundred lines per second, preferably about 400-1000 lines per second, and are stored in a buffer 25. Buffer 25 may, for example, be implemented with about one megabyte of VRAM, corresponding to somewhat under one minute of raw image frame data at that sampling frame rate. Each sampled image represents a frame of digital information at a unique moment in time, and may illustratively have the format of an ordered data string with a pixel value for each of a thousand successive pixels forming the line array. As set forth in greater detail below, the frames from the sensor and residing in the buffer are further processed in the camera to form the camera output stream.

the frames acquired in the buffer 25 to detect object information in the image, and, responsive thereto, annotate or control the image data output on the output signal line 28 for connection to an external image management system 16. It will be understood that line 28 is shown for purposes of illustration as a line, but is more generally to be understood to be a communication link, such as a local radio frequency link so that the camera may alternatively send its data output by RF transmission.

Several representative object detection operations will now be illustratively presented. It will be familiar to those in the art that two-dimensional (*line x time*) image frames created by an event recording line camera appear smeared in the width direction, with the *x*- or width dimension proportional to the dwell time of the object at the imaged object line L or FL, and inversely proportional to the speed of the object crossing that line. Conversely, background field, when not obscured by a contestant passing in front of it, remains always the same, forming horizontal bands of fixed color or intensity passing through each pixel position of the line sensor 20. These are the image frames in buffer 25 upon which the object detector described below operates. Preferably each line image frame is marked with a time reference, so that this time information appears within the digital information of the frame. In a preferred embodiment, the time reference for each frame is indicative of the time the camera 12 captured the picture. This may be an absolute time, or a time relative to the start of an external event or trigger signal, and it may be derived from other signals, such as the signal from a start detection sensor 84 (FIGURE 1), or an external time source, or an internal camera timer, preferably with a system time synchronization protocol as described in applicant's aforesaid patents.

In general, the external computer storage and image analysis system 16 may include elements such as software for adding text or linking images with identifying data to index the raw image data, and for indexing, accessing, and quickly displaying and analyzing the times appearing in the image data. Systems of this type are extensively described in the aforesaid two commonly owned U.S. Patents.

By way of context, the main control computer 16 of the external management system may have a central processor 40 that processes the blocks of information stored within an internal memory 36 and organizes the line frames into two-dimensional image frames for displaying the scene and time contents of a sequence of digital line frames on a display monitor 42. The central processor 40 preferably also controls the automatic operation and memory management of the system 10, and

line, such as a wall, is imaged identically in successive line images, so that when a frame is assembled from successive lines, the background appears as horizontal stripes each having the fixed color or intensity of the imaged stationary feature.

FIGURE 3 illustrates a typical image frame formed in this fashion of a group of runners crossing a finish line. Among the artifacts due to the mode of generation of this image, it is apparent that the background appears as a set of horizontal stripes when not occluded by a runner, and each runner appears frozen in the exact posture he assumed as successive strips of his body crossed the finish line. Nonetheless, except for a slight dimensional stretching or compression effect along the lateral direction, each runner appears approximately as in a normal spatial image taken from the perspective of the fixed camera position. Thus his suit color, entry number, facial traits and other identifying features are, or would be, captured in the image.

Returning now to a description of camera operation, each digital line frame captured by the system 10 of FIGURE 1A is stored in the buffer 25, and the control microprocessor 22 operates on this line image data to control the camera output. The invention contemplates several different forms of object recognition and output control, examples of which will now be described. First among these is the recognition of an object moving across the line FL.

FIGURE 4 is a flow chart illustrating this operation in a basic prototype embodiment of the invention. In this embodiment, the microprocessor 22 in the camera processes raw image frames from the buffer 25 to detect the presence of an object moving across the line field of view, and it controls the output data stream so that the image frames are sent out by the camera only when there is finish line activity, while precision time marking is maintained. In terms of hardware, the microprocessor loads the line frames into VRAM of moderate size, e.g., a 2MB VRAM, and then processes successive lines to detect finish line activity. In a further aspect, when a pattern of probable motion is detected, the processor confirms the pattern, and retroactively tags the start of the active image sequence for transmission out of the camera, while inactive frames or "dead time" images are simply compressed, deleted, or even sent to tape backup without occupying system bandwidth.

In addition to the buffer storage or VRAM, the camera's internal microprocessor 22 preferably has a RAM capacity of about 32MB or more, allowing the camera itself to store up to several minutes of time-resolved active finish line images.

time $t_0$ of the first line of the current block. In alternative embodiments, the processor may wait for two, or more generally $n$ blocks in a row to differ, so that it confirms the sustained presence of an object before it annotates the image data or sets an output control signal. In that case the camera starts counting, and when the block value remains different and above the threshold for at least, e.g., five consecutive blocks in time, the change is recognized as being due to an object moving across the field of view. The processor retroactively sets the BEGIN-OBJECT flag at the start of the active sequence. The flag data may be sent as a separate data indication along with the continuous image data stream to facilitate external processing and indexing of the line image data, or the flag data may be used to directly initiate the output of image data from the camera commencing at time $t_0$, so that image data is sent to the output port only when an object has been detected. In another embodiment, the camera may be set to catch the image data starting at a preset time before the first detected change frames, for example at .1 seconds before the first detected change, so that the finish line sequence will include images as the contestant nears the finish and shows the first parts of a contestant crossing. Thus, the nose of a horse, or hand of a runner, will appear before the torso breaks the ribbon. Such details, while coming earlier than the event which is traditionally recognized as crossing the line, are useful for resolving ambiguities when multiple contestants cross nearly simultaneously. For example, a projecting hand may be followed to identify the position of a contestant even when the torsos of several contestants are simultaneously occluded or overlapping in the field of view. Thus, the active image sequence may be set to include a fixed leader portion.

As further shown in FIGURE 4, once the runners have been detected in the image the processor then switches to a different analysis procedure which monitors or analyzes the object now appearing in the image frames to derive additional information. In a basic embodiment, the processor continues processing sample image strips in a manner somewhat analogous to the initial object-trigger analysis, to determine when the object has passed or the finish line activity ceases. A suitable set of determinations is shown in FIGURE 4A for this aspect of the processing. When the end of the object is detected, the processor then sets an END OF OBJECT flag, preferably causing the output controller to turn off the output stream or enter a dormant mode. For this latter detection, the processor detects whether all pairs of blocks differ by less than a threshold $T_2$. Advantageously, the processor may employ a different threshold, $T_2 < T_1$ or may require that a sub-threshold level of homogeneity persist for a greater number of sample strips, or both, before concluding that the moving objects have passed. This operation avoids falsely signaling the end of a sequence when in fact a relatively

In addition to flagging the active segment of the image data generated by the camera's line sensor, the invention contemplates further internal processing of identified object to produce object-based data. This is shown schematically in FIGURE 5. Two distinct types of data will be briefly illustrated. One is object identification, which proceeds by way of image analysis subroutines to detect color, number, bar code or other individual features of the contestants as they pass. This is discussed in greater detail below. The second, which will now be discussed, may be called "photocell determinations". In accordance with this latter aspect of the invention, the in-camera processor performs a more detailed image analysis of the object-containing frames to fit the contestant to a template, recognizing defining parts of the body, and then applies a species/event specific interpolation or estimation rule to determine the probable crossing time.

As applied, for example to a horse, the processor may process direct-overhead image lines to detect the body of a horse crossing the line, then, while correcting for frame rate and event speed (which affects the horizontal distance scale), identify the crossing time by the frame which occurred a fixed time or distance before the mid-point of the body. This estimation procedure will produce an estimated time, based on a standard species size and shape, which can be used for initial announcement scoreboard displays. For example, the processor may set the "nose" of a horse to be 1.6 meters ahead of its center, or the nose of a greyhound to be .7 meters ahead of its center. By adding the identified time to the image output data stream, an immediate index is provided to the race management system, and full-frame images may be immediately constructed and reviewed to determine the exact crossing time. Inspection of FIGURE 3 shows a typical crossing configuration for a human track event. As applied to a person, the relevant image analysis may be triggered by the initial appearance of a hand, arm or leg in the field. In that case, the image analysis may proceed by a fixed rule, such as setting the probable crossing to be about 30-50 centimeters after the initial limb, or it may proceed with further image analysis to detect the central mass of the body, e.g., the torso or stomach, and to set the estimated crossing time at the appearance of this feature. A race official would then view the image frames so identified to determine the exact crossing time by observing, for example, whether the torso were angled forward, and seeing which line of the composite frame actually contained the leading edge of the torso. Other photocell crossing determinations may be readily implemented by employing rules specific to the speed of the event and the species of contestants.

colors at once. The invention also contemplates systems wherein a special identification marker is worn by each contestant so as to be visible in the image. Thus, for example, when used for an equestrian event, the markers may be attached to the top of each horse's back, and the camera may image the finish line (or an intermediate station along the track) from directly overhead so that all markers are oriented directly toward the camera and no marker is ever blocked by the adjacent runners. Such markers may include, for example, oriented bar codes, or lines or blocks of different colors forming a distinctive combination. The color markings may also be advantageously shaped to assure quick and dependable detection. This may be done, for example by arranging the different colors in color bands which are oriented in a manner to assure that they are imaged on separate detection pixels of the camera or have a substantial dwell time on the detecting pixels. For example, the bands may be worn parallel to the direction of motion, giving them an extended dwell time in the image, and be offset across the direction of travel so that they are imaged onto different pixels of the sensor. They may also, where size permits, be offset along the direction of travel, leading to temporal resolution of the color combination in the image. This makes them readily detected when the line images are sampled in blocks of narrow height along the image sensor or are imaged for only a short time duration.

In yet other embodiments, the processor may incorporate an optical character recognition module to simply read the number on a contestant's jersey, or may process the image lines using patterns of a bar code reader to recognize bar code identifiers. In general, however, the use of a mark configured for line-camera detection, and preferably color identification markers is preferred to the use of character or bar code technology, in order to reduce the possibility of occlusion and misreading of the sought-for markers.

When used as an event recording system, such as at the finish line of a race, the object triggered line scan camera system of the present invention may be operated to record and resolve positions one thousandth of a second apart, or less, while greatly reducing the real time bandwidth demands imposed on external system elements, and without introducing any noticeable delay in the transmission of necessary image data. The data annotation of output frames, even without physical cropping of static or dead time images, also results in a system wherein the data handling and RAM storage demands placed on the external race management system are reduced.

Claims

1. An event recording camera system for forming a time sequence of images, comprising

a camera which generates a first sequence of digital line image frames of a fixed position in space, each frame of said first sequence representing a line image view that is captured by said camera at a moment in time and imaged onto an array of detector elements, said first sequence including active segments imaged at times wherein moving objects cross said fixed position, and inactive segments wherein no moving objects cross said fixed position

a buffer in said camera for storing said first sequence of frames as they are generated, and

a processor in said camera operative on said first sequence to detect an object and produce an object detection signal so as to selectively present said active segments at a camera output.

2. A system according to claim 1, wherein said processor communicates with the buffer to receive data from frames of said first sequence and compare data from successive frames to detect an object, such that said processor retroactively identifies start of an active imaging segment.

3. A system according to claim 1, wherein frames of the active imaging segment include frame time information.

4. A system according to claim 1, wherein said processor communicates with the buffer to receive data from frames of said first sequence and compare data from successive frames to detect end of an object, and sets the end of an active imaging segment.

5. A system according to claim 1, wherein the active imaging segment includes object identification information.

6. An event recording digital camera including an optical imaging element for forming a light image of a restricted visual field, and an image sensing

13. A digital camera according to claim 12, wherein the processor annotates the image data stream with data codes indicative of at least one of start of object, end of object, and identity of object.

14. A digital camera according to claim 12, wherein the processor controls output of the camera to selectively pass image frames containing moving object images.

15. An event recording video camera comprising

means for imaging a visual field

a line sensor for converting a line portion of the imaged visual field into electrical signals representative of pixels of the image of said field

circuit means for processing said electrical signals to form a digital output stream containing digitized pixel values of a sequence of frames at a high scanning rate

a buffer for storing said digital output stream before transmission, and

a processor operative on contents of the buffer for comparing sets of data from the buffer and identifying image data associated with moving objects, said processor controlling said output stream responsive to the identified data.

16. A video camera according to claim 15, wherein said processor compares block sum light values to detect beginning or end of object motion in the visual field.

17. A video camera according to claim 15, wherein said processor image-processes blocks of frames to detect an object identifier and controls said camera to transmit image data annotated with an indication of object identifier.

18. A video camera according to claim 15, wherein said processor image-processes blocks of frames to detect an object feature and controls said camera to transmit image data and estimated crossing time data.

19. A video camera according to claim 15, wherein said pixel values include color values and said processor processes values for each color separately.

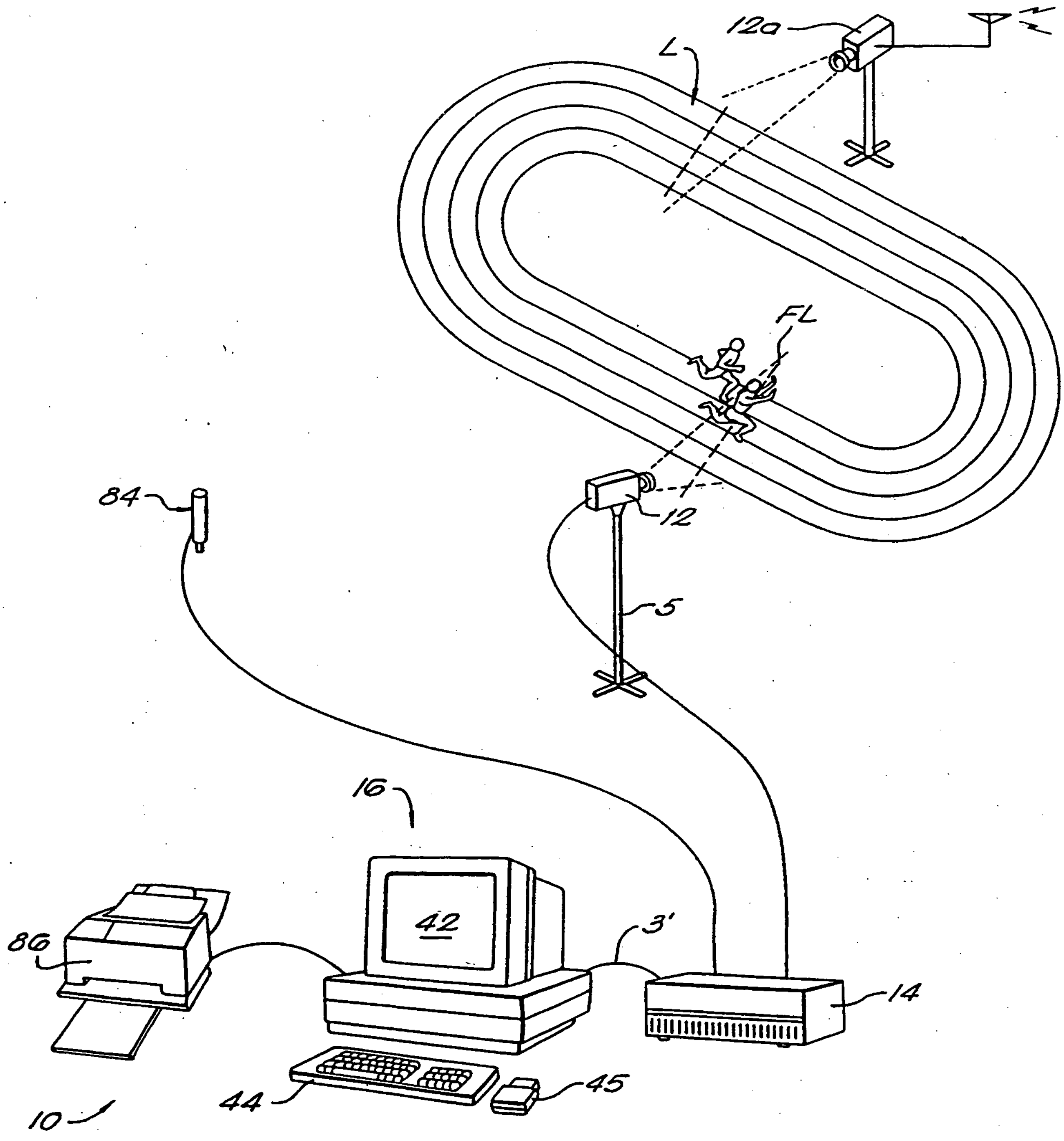



FIG. 1

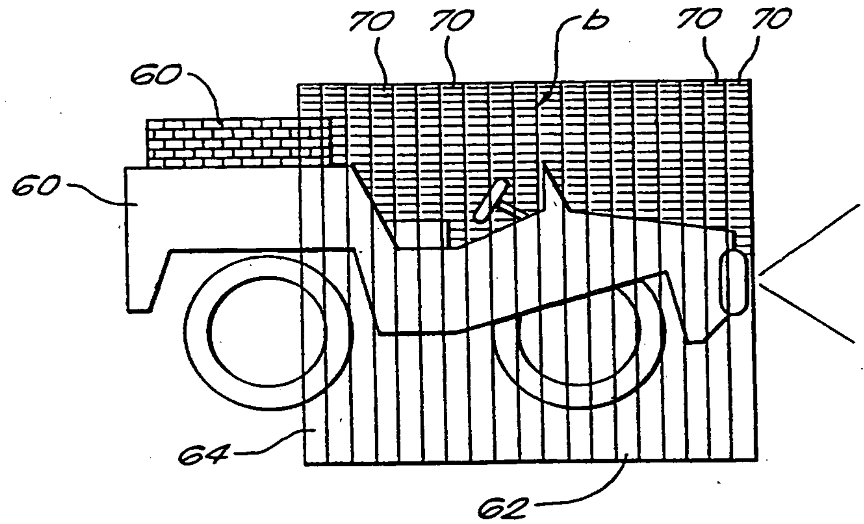



FIG. 2

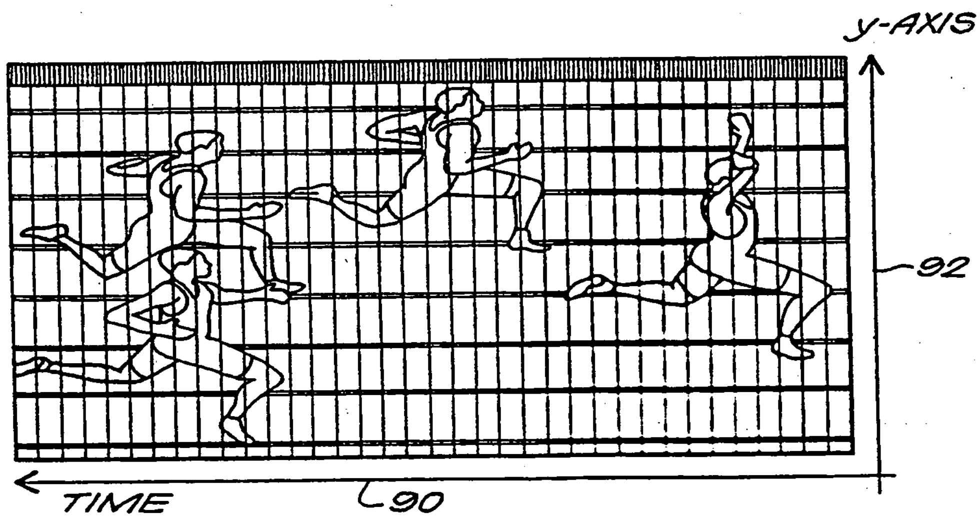



FIG. 3

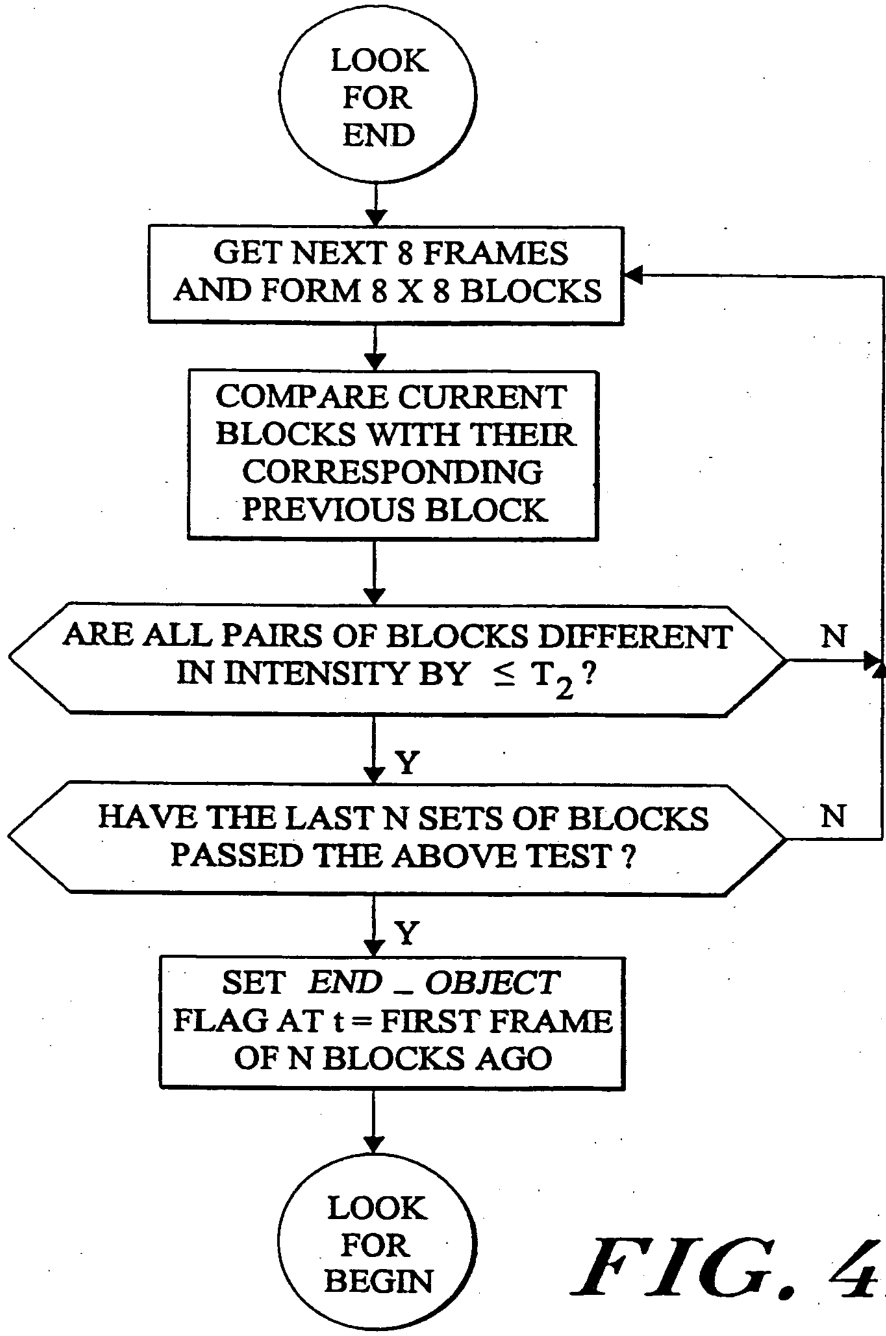

LOOK FOR END
GET NEXT 8 FRAMES AND FORM 8 X 8 BLOCKS
COMPARE CURRENT BLOCKS WITH THEIR CORRESPONDING PREVIOUS BLOCK
ARE ALL PAIRS OF BLOCKS DIFFERENT IN INTENSITY BY $\leq T_2$?
N
Y
HAVE THE LAST N SETS OF BLOCKS PASSED THE ABOVE TEST ?
N
Y
SET *END _ OBJECT* FLAG AT t = FIRST FRAME OF N BLOCKS AGO
LOOK FOR BEGIN

*FIG. 4A*

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/07596

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :H04N 5/225, 5/235, 5/445, 7/18
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/135, 142-145, 157, 207, 209-210, 220, 222, 239, 563-564, 569; 340/

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

N/A

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 5,057,925 A (TSUTSUI et al) 15 October 1991, see entire document. | 1-20 |
| A | US 5,136,283 A (NOBS) 04 August 1992, see entire document. | 1-20 |
| A | US 5,280,363 A (NAKAMURA et al) 18 January 1994, see entire document. | 1-20 |
| A | US 5,493,331 A (TAKAHASHI et al) 20 February 1996, see entire document. | 1-20 |
| A | US 5,552,824 A (DEANGELIS et al) 03 September 1996, see entire document. | 1-20 |
| A | US 5,630,186 A (YAMAGUCHI et al) 13 May 1997, see entire document. | 1-20 |

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/07596

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

348/135, 142-145, 157, 207, 209-210, 220, 222, 239, 563-564, 569; 345/196; 358/482-483; 386/121; 382/192-194, 282, 291